Double Spin Asymmetry
of Single Electron Production
at PHENIX Experiment

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for the PHENIX collaborator

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Internal Structure of a Nucleon

- **Internal structure of a nucleon 〜parton model 〜**
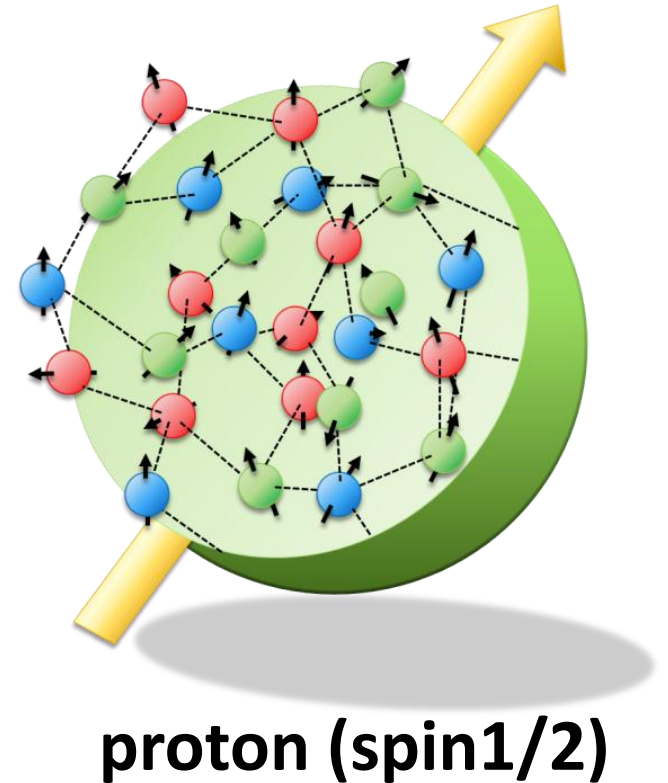 - discovery of Bjorken scaling law
    - establishment of the parton model
    - Bjorken x : the momentum fraction of parton
  - total momentum fractions for each parton
    - $U:D:g$ 〜 36%: 18%: 46%
- **proton spin puzzle**

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

proton spin　　　quark spin　　gluon spin　　orbital
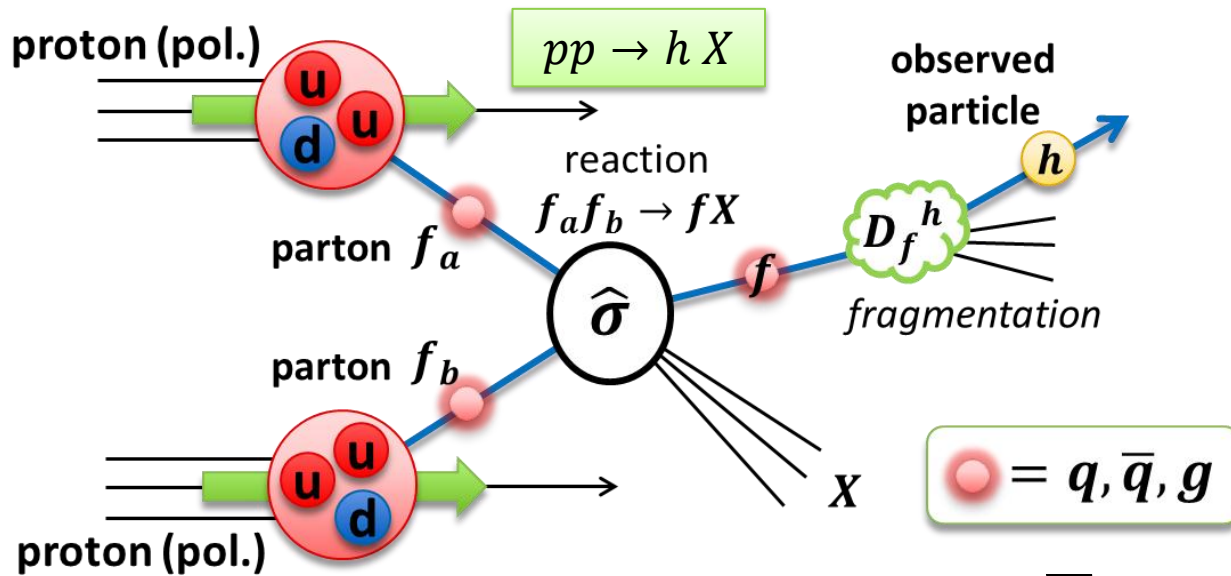
  - Deeply Inelastic Scattering (DIS) experiment
  - $\Delta\Sigma$〜25% !?

- ***Large contribution from gluon polarization ?***

proton (spin1/2)

$\bigcirc: u(\bar{u})$ $\bigcirc: d(\bar{d})$ $\bigcirc: s(\bar{s})$ ⋯: g

ΔG Measurement in Polarized *p-p* Collisions

double spin asymmetry : $A_{LL} \equiv \dfrac{\sigma_{++}^{h} - \sigma_{+-}^{h}}{\sigma_{++}^{h} + \sigma_{+-}^{h}} = \dfrac{\displaystyle\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}{\displaystyle\sum_{a,b} f_a \otimes f_b \otimes \hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$

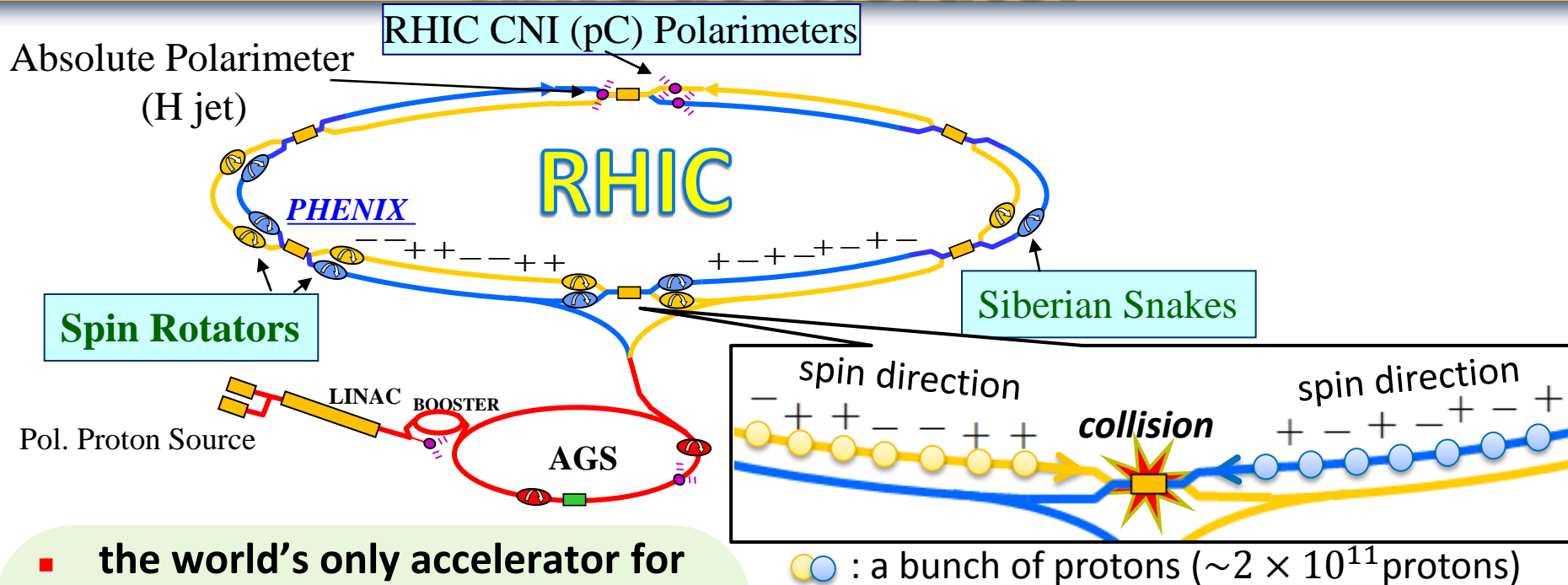- **gluon polarization Δg can be accessed with the double spin asymmetry A_{LL}**

Brookhaven National Lab. (U.S.)
RHIC accelerator

Brookhaven National Lab. (U.S.)
RHIC accelerator

RHIC CNI (pC) Polarimeters

Absolute Polarimeter (H jet)

RHIC

PHENIX

− − + + − − + +   + − + − + − + −

Siberian Snakes

Spin Rotators

LINAC   BOOSTER

Pol. Proton Source

AGS

spin direction   collision   spin direction

− + + − − + +   + − + − + − +
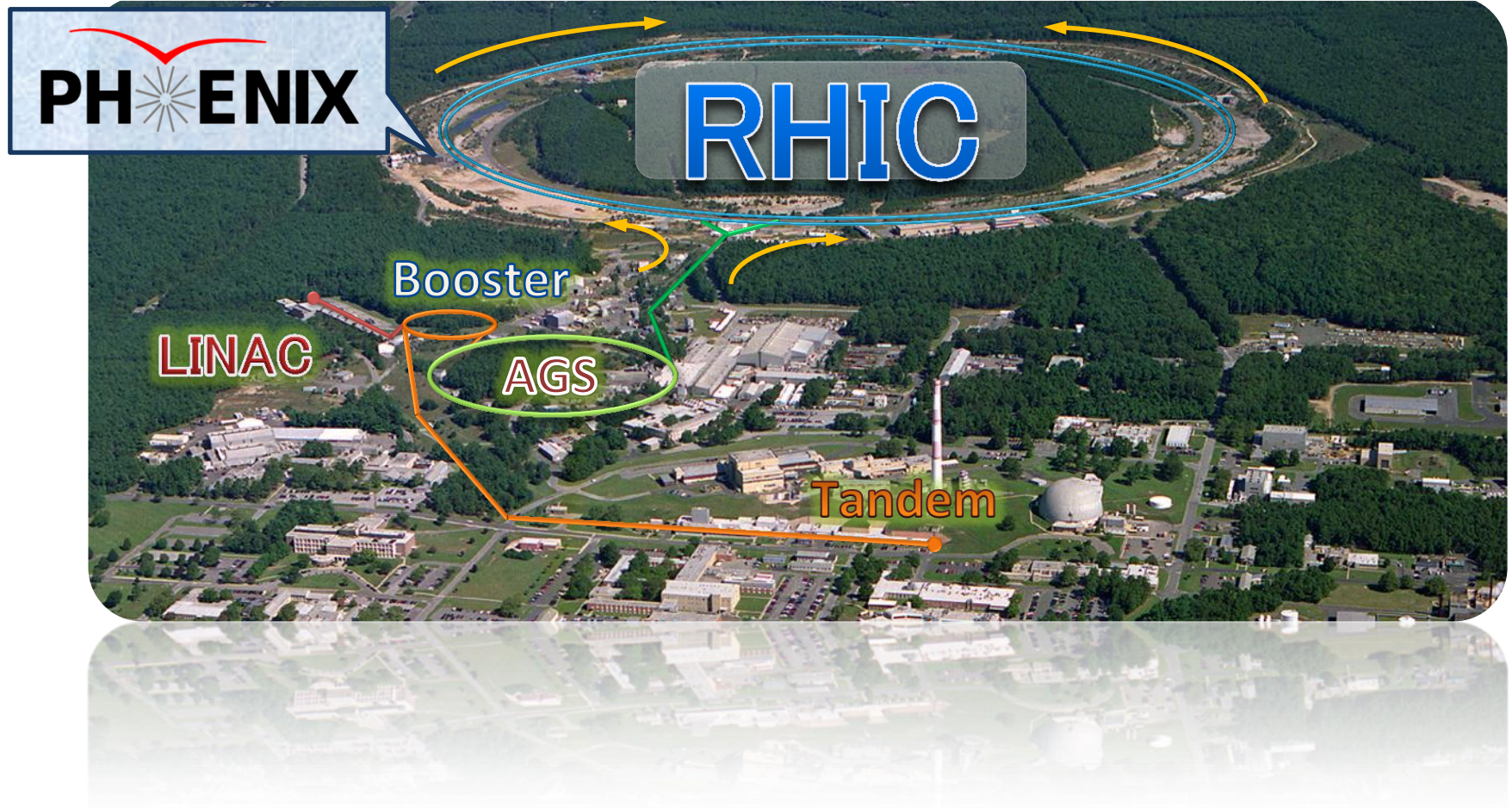
- **the world's only accelerator for the polarized proton collisions**
  - bunch-by-bunch spin direction is different

🟡🔵 : a bunch of protons ($\sim 2 \times 10^{11}$ protons)

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

N : yield of the specific particle

$R \equiv \dfrac{L_{++}}{L_{+-}}$: relative luminosity
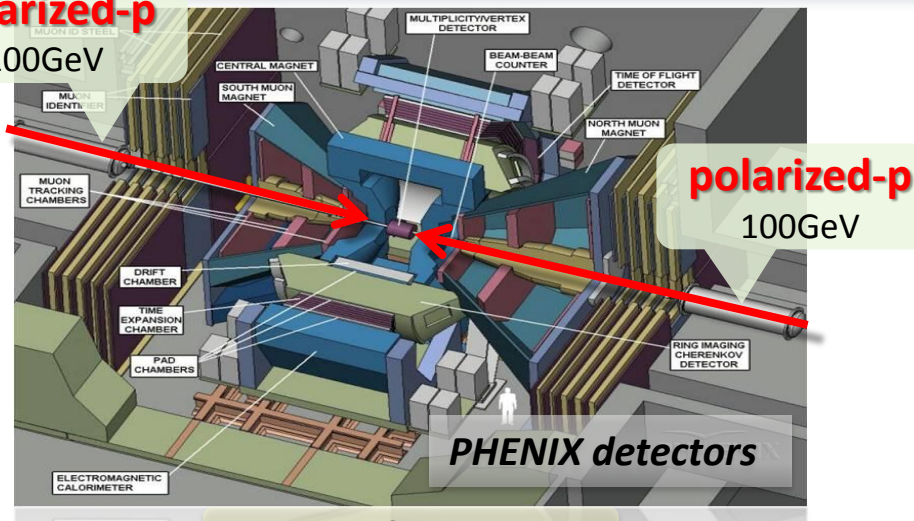
$p\text{-}p$ $\sqrt{s} = $ 200GeV performance at PHENIX

Year	polarization(%)	$L_{analyzed}$ (pb^{-1})	FOM (P^4L)
2005	50	2.5	0.15
2006	57	6.5	0.66
2009	**57**	**14 [6.1]**	**1.5 [0.64]**

[***]: for heavy quark measurement

RHIC PHENIX detector

polarized-p
100GeV

polarized-p
100GeV

PHENIX detectors

2010

EM. Calorimeter

drift chamber

pad chamber

e

HBD

RICH

PHENIX (Central Arm region)

– pseudrapidity: $|\eta| < 0.35$
– azimuthal coverage: $\Delta\phi = 2 \times \pi/2$

- **Drift Chamber + Pad Chamber (DC + PC)**
  – tracking & momentum reconstruction for charged tracks

- **RICH Counter**
  – electron identification

- **Electromagnetic Calorimeter (EMCal)**
  – energy measurement for electrons & photons

- **Hadron Blind Detector (HBD)**
  – a new detector for further electron identification
  – BG rejection for the electron measurement
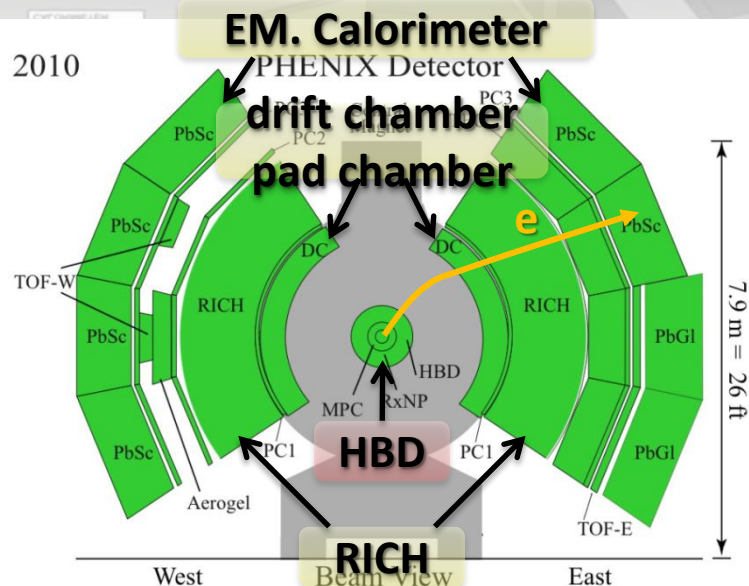
Current A_{LL} Results at PHENIX

A_{LL} of π^0 production

- **The most abundant probe in PHENIX**
- **The largest constraint for ΔG**

    – uncertainty from fragmentation functions since it is a combination of g-g, g-q and q-q reactions

A_{LL} of π^0 production

PRL 103(2009)012003
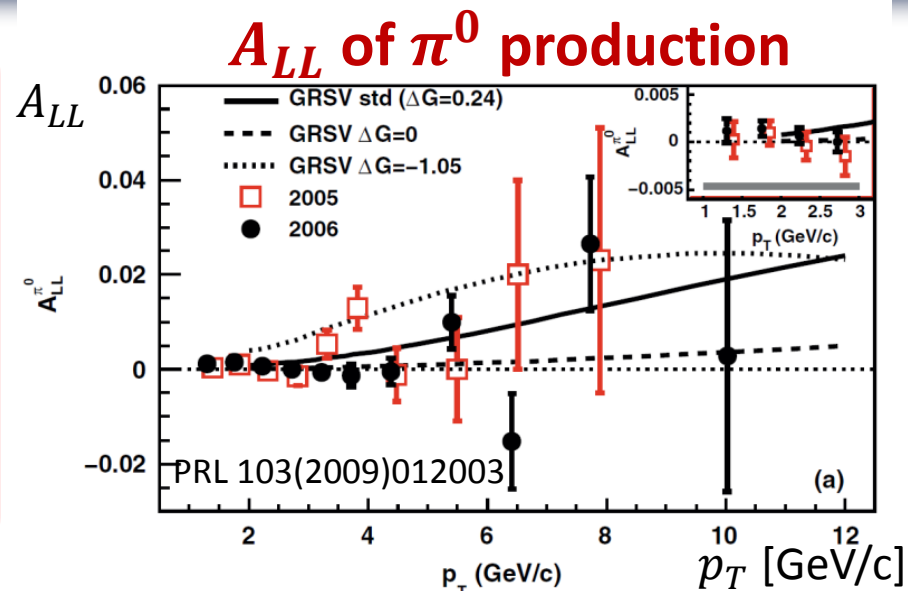
A_{LL} of direct γ production

- **only q-g in leading order**
    – direct sensitivity to size and sign of ΔG
- **no fragmentation effect**

    – low statistics due to QED process

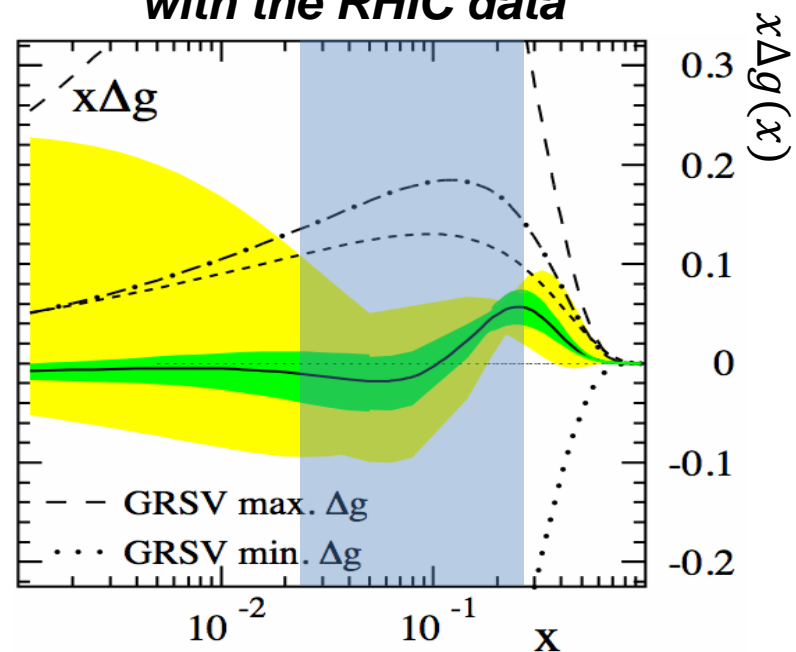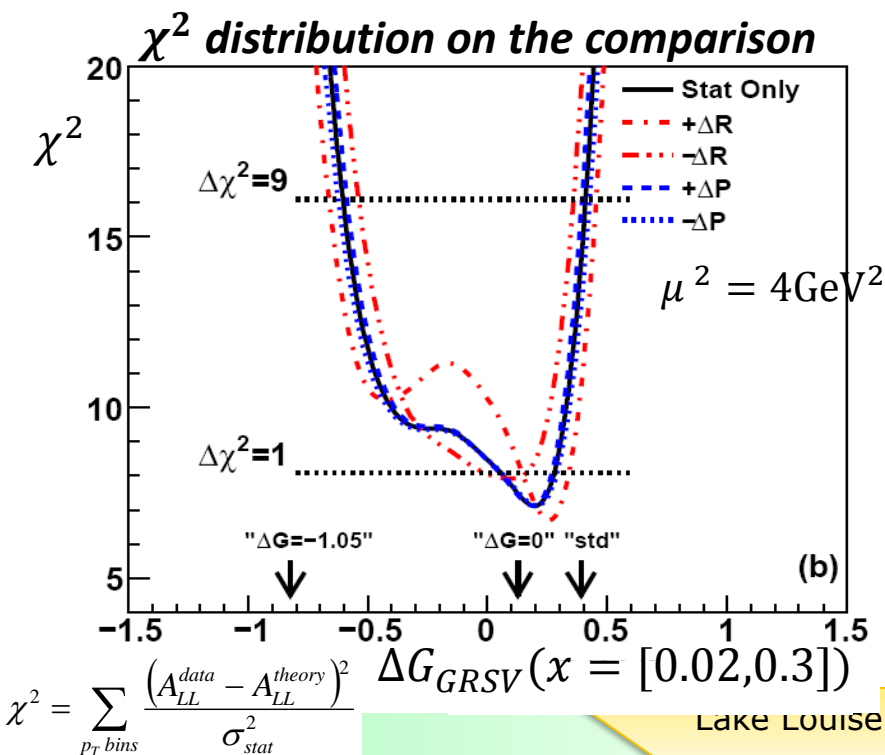### A_{LL} of direct γ production
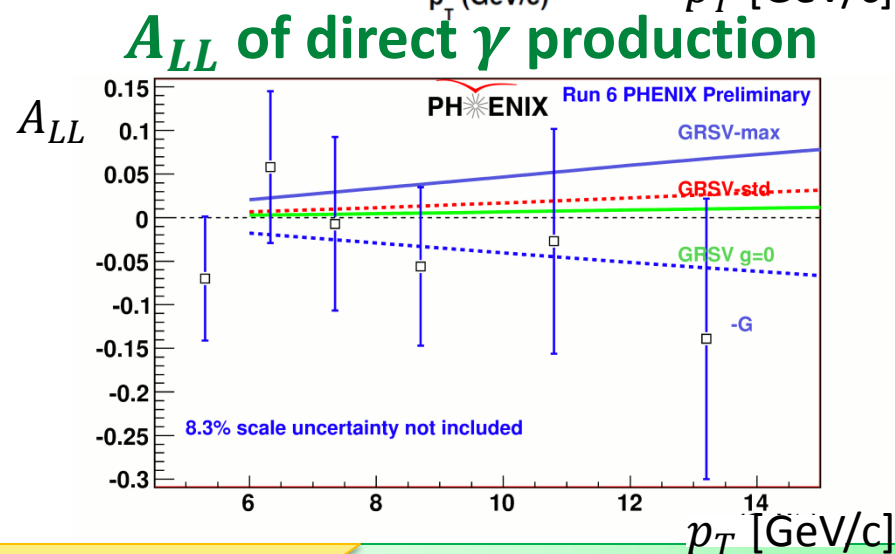
Current Constraints on ΔG from $A_{LL}^{\pi^0}$

- **Compare $A_{LL}^{\pi^0}$ with GRSV calculation**
  - GRSV: a model of $\Delta g(x)$ function form

- **prefer small ΔG value**
  - small model dependence

- **Global fitting result of $\Delta g(x)$ with DIS + RHIC data**
  - node structure ?

significantly constraint region with the RHIC data

χ^2 *distribution on the comparison*

Stat Only
$+\Delta R$
$-\Delta R$
$+\Delta P$
$-\Delta P$

$\Delta\chi^2 = 9$

$\mu^2 = 4\text{GeV}^2$

$\Delta\chi^2 = 1$

"$\Delta G = -1.05$"   "$\Delta G = 0$" "std"

(b)

$\Delta G_{GRSV}(x = [0.02, 0.3])$

$$\chi^2 = \sum_{p_T \ bins} \frac{\left(A_{LL}^{data} - A_{LL}^{theory}\right)^2}{\sigma_{stat}^2}$$

$x\Delta g$

GRSV max. Δg

GRSV min. Δg

$x\Delta g(x)$

x
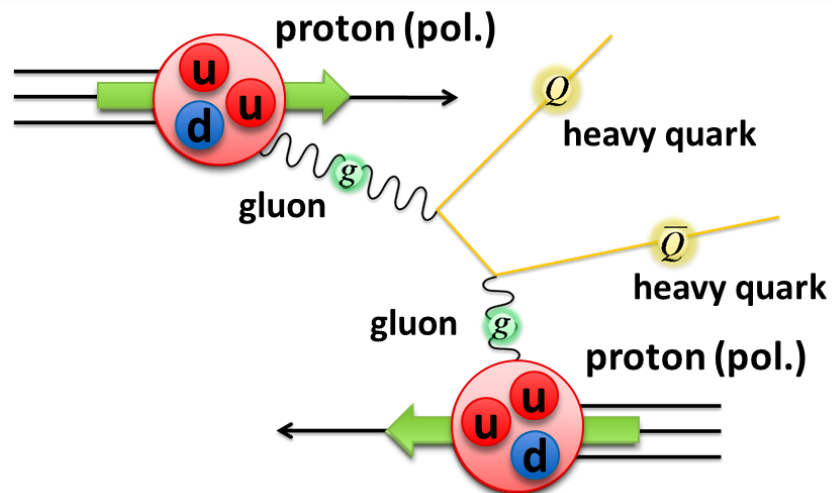
fitting error: $\Delta\chi^2 = 1$ (optimistic)

$\Delta\chi^2/\chi^2 = 2\%$ (conservative)
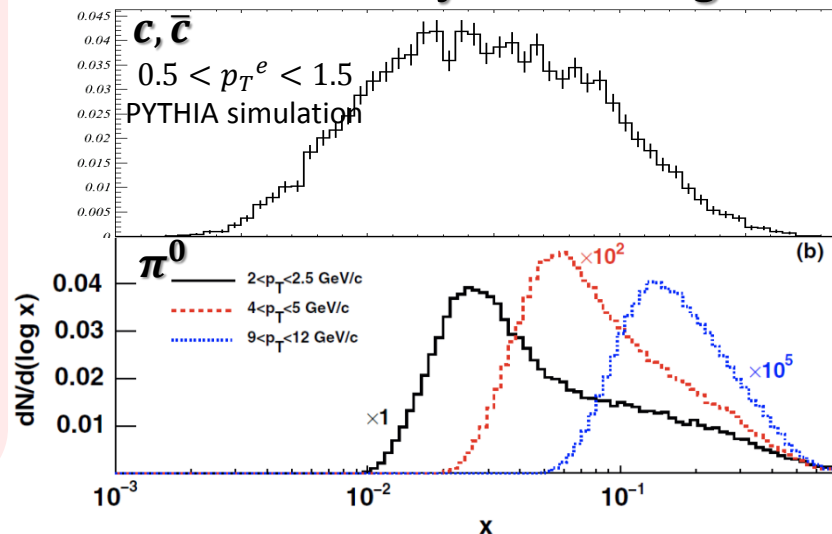
A_{LL} of Heavy Quark Production

$$A_{LL}^{\text{Heavy Quark}} \equiv \frac{\sigma_{++}^{HQ} - \sigma_{+-}^{HQ}}{\sigma_{++}^{HQ} + \sigma_{+-}^{HQ}}$$

$$\sim \frac{\int \Delta g \otimes \Delta g \otimes \Delta\hat{\sigma}^{gg \to QX} \otimes D_Q^h}{\int g \otimes g \otimes \hat{\sigma}^{gg \to QX} \otimes D_Q^h}$$

A_{LL} of heavy quark production

- **g-g scattering is dominant process**
  - **direct measurement for the gluon polarization**
  - **small uncertainty from FF**
- **hard process due to large mass**
  - **validity of pQCD**
- **a suitable channel to measure the gluon polarization**

proton (pol.)

u u d

heavy quark Q

gluon g

heavy quark Q̄

gluon g

proton (pol.)

u u d

distribution of Bjorken x of gluons

$c, \bar{c}$
$0.5 < p_T^e < 1.5$
PYTHIA simulation

π^0
- 2<p_T<2.5 GeV/c
- 4<p_T<5 GeV/c
- 9<p_T<12 GeV/c

$\times 1$ $\times 10^2$ $\times 10^5$
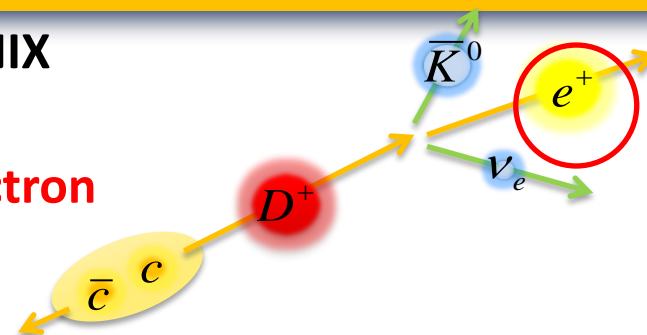
(b)

dN/d(log x)

x

A_{LL} of Single Electron Production

- **measurement of the heavy quark at PHENIX**
  - detect an electron from heavy meson decay

$$\begin{cases} D^+ \to \overline{K}^0 \, \nu_e \, e^+ \\ D^0 \to \overline{K}^- \, \nu_e \, e^+ \end{cases}$$ **single electron**

- **spin asymmetry of the single electron production**
  - asymmetry of inclusive (Signal+BG) electron production A_{LL}^{S+BG}

$$A_{LL}^{\text{single e}} \approx \frac{1}{D} A_{LL}^{\text{S+BG}} \qquad D \equiv \frac{N_e^{\text{single e}}}{N_e^{\text{S+BG}}} : \text{Signal Occupancy}$$

  - *__BG reduction for large Signal Occupancy is important for the measurement of the spin asymmetry__*
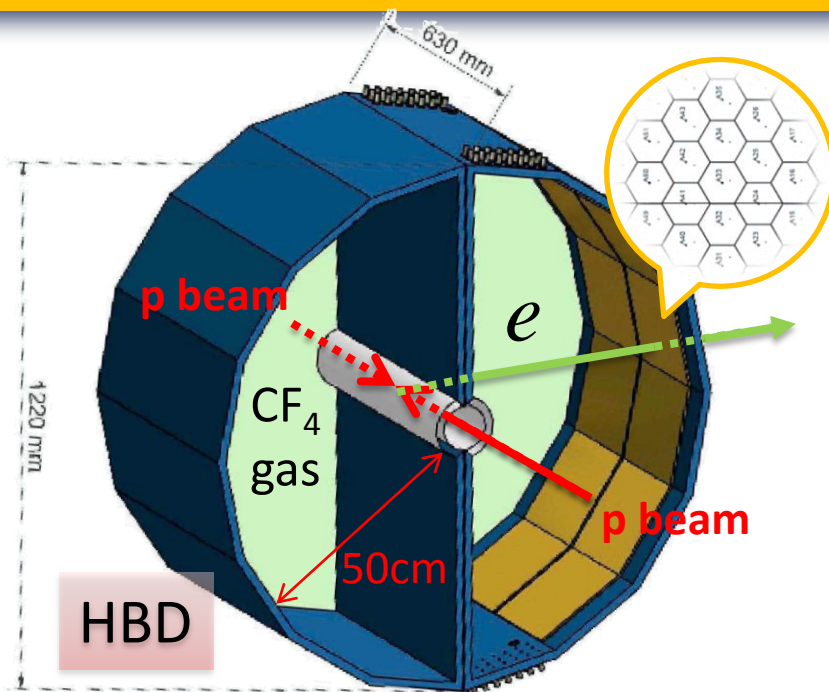
| **photonic electron**	**non-photonic electron**
▪ **photon conversion** $\pi^0(\eta) \to \gamma\gamma,$ $\gamma \to e^+e^-$ **(in material)** ▪ **Dalitz decay** $\pi^0(\eta) \to \gamma e^+e^-$	▪ **heavy meson decay** $D \to e^\pm + X$ **(signal)** ▪ **Kaon decay :** $K^\pm \to \pi^0 \nu_e e^\pm$ ▪ **vector meson decay :** $V \to e^+e^-$

Hadron Blind Detector (HBD)

630 mm

1220 mm

p beam

e

CF_4 gas

p beam

50cm

HBD

single electron

photonic electron (electron pair)

e

D

e^+

e^-

γ

pair mass ~ 0

B field ~ 0

HBD cluster charge distributions

each histograms are normalized as integral=1(or0.1)

75%

~20%

accept

HBD cluster charge distribution
- single e cluster
- merged cluster
- hadron cluster × 0.1

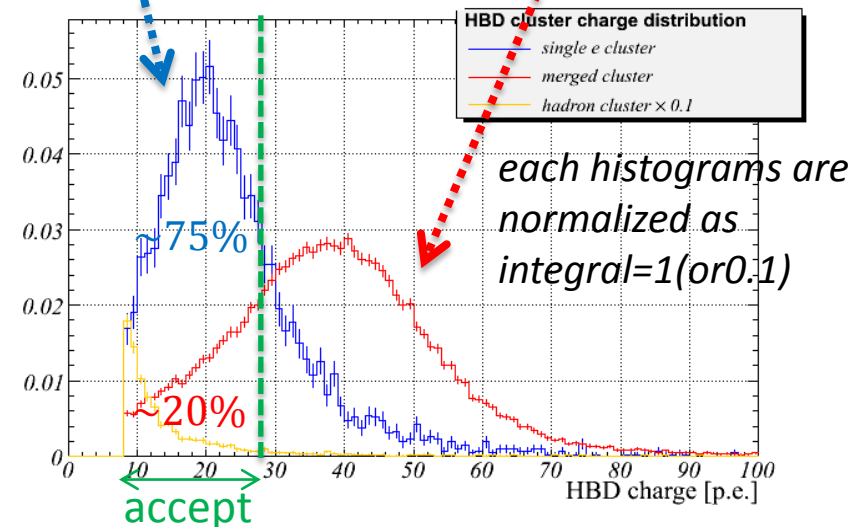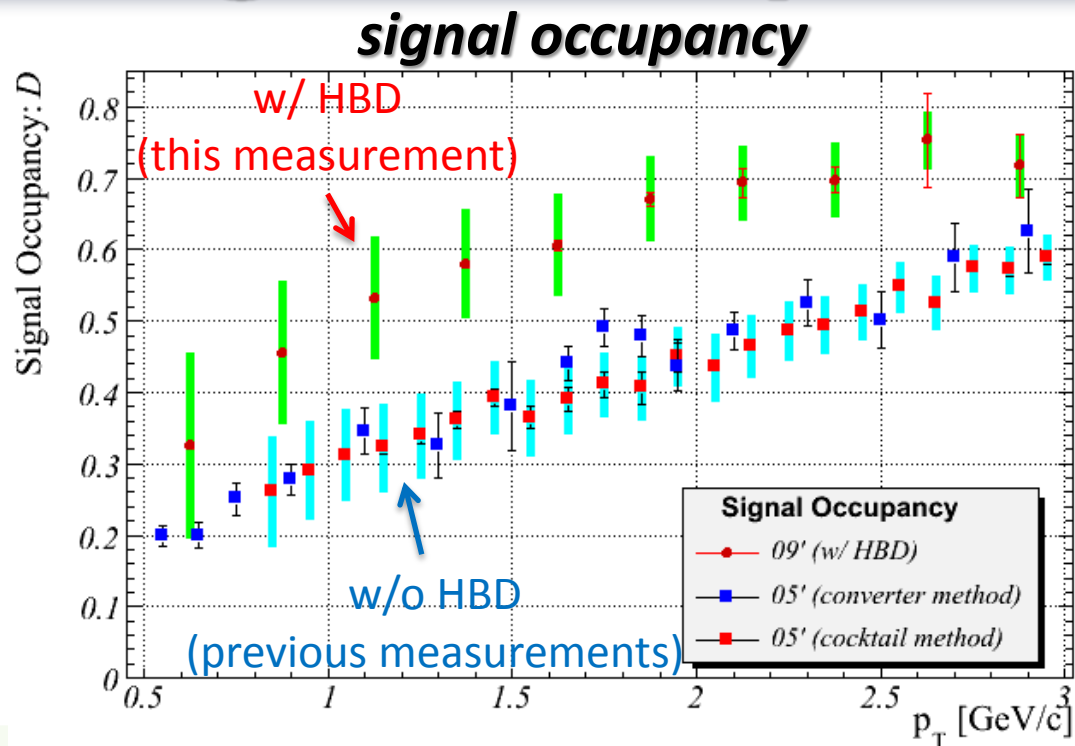HBD charge [p.e.]

- **Hadron Blind Detector**
  - gas Cerenkov detector read out with CsI evaporated GEM
  - *electron identification*
- **this analysis is the first time of physics measurement with HBD**
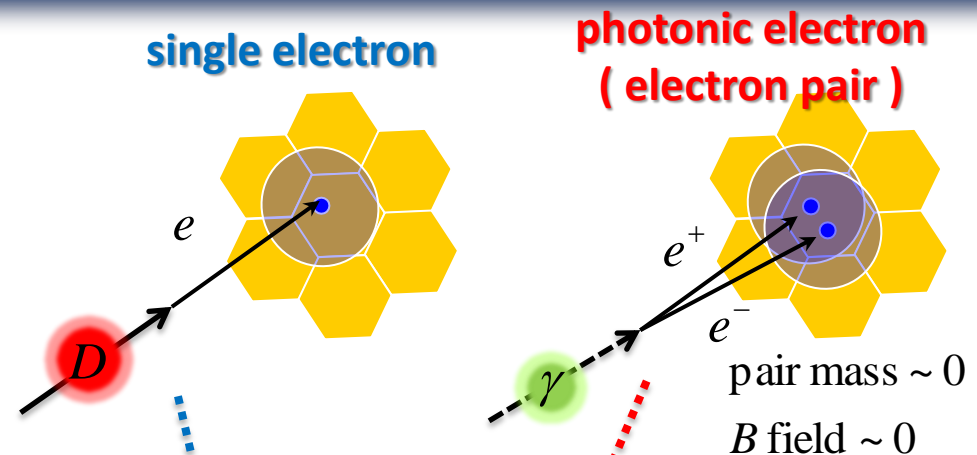
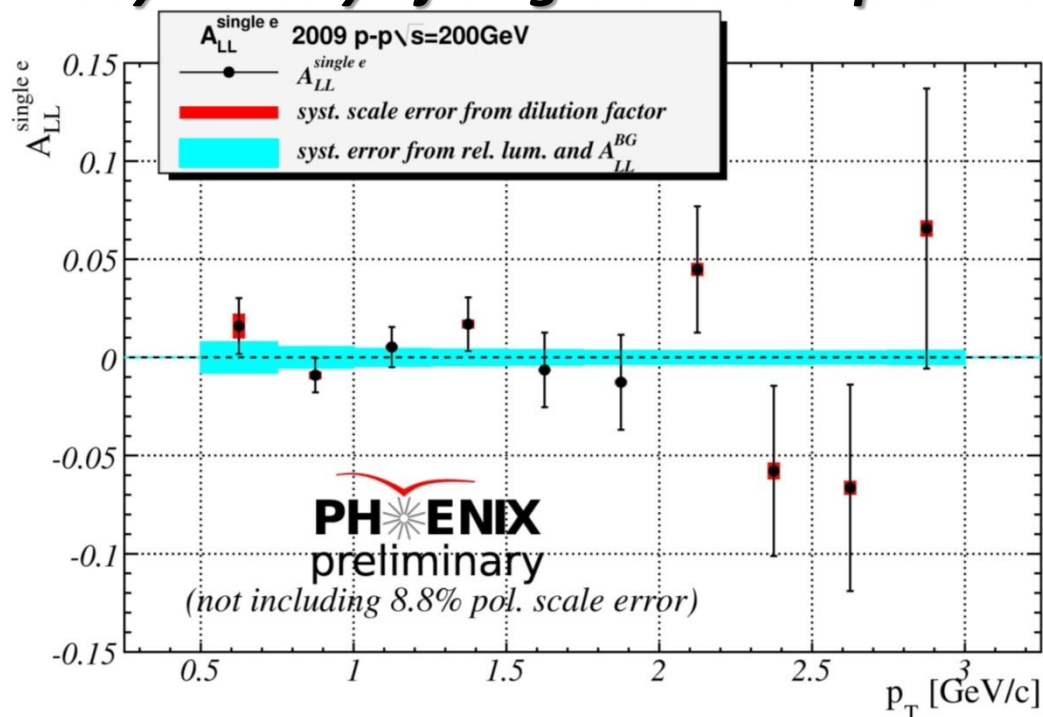# measurement of spin asymmetry of single electron production

signal occupancy

- ## Signal Occupancy: *D*
  - the important value for the asymmetry measurement
  - increase by about *factor of 1.5* from previous measurements due to the HBD performance

Spin Asymmetry for Single Electron Production

spin asymmetry of single electron production

- **success of an approach to $\Delta g/g(x)$ by using the very clean channel**
  - $A_{LL}{}^{single\ e}\ (0.5 < p_T < 1.5\ \mathrm{GeV/c}) = (\ 3.1 \pm 5.5^{stat.} \pm 5.7^{syst.}\ ) \times 10^{-3}$
  - **estimation of the constraint for $\Delta g/g(x)$ from the result is on going now**

Summary

Summary

- **Spin asymmetry of single electron production is a suitable probe to measure the gluon polarization in a proton.**
  - directly access to gluon property in a proton
  - small uncertainties from fragmentation functions

- **New detector HBD increases the "Signal Occupancy" by a factor of about 1.5 compared with previous measurements**
- **The approach to the $\Delta g/g(x)$ with the clean probe is succeeded.**
  - $A_{LL}{}^{single\ e}\ (0.5 < p_T < 1.5\ \text{GeV/c}) = (\ 3.1 \pm 5.5^{stat.} \pm 5.2^{syst.}\ ) \times 10^{-3}$

Future Prospect

- **estimation of constraint on $\Delta g/g(x)$ from the result is on going now**

backup slides
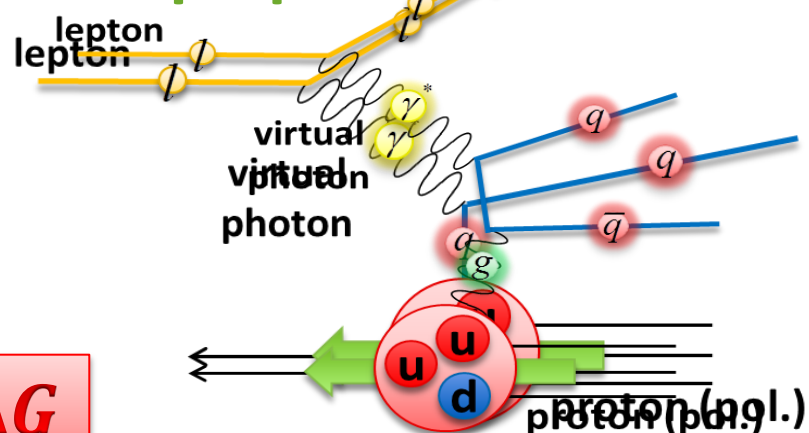
ΔG Measurements

DIS experiment

- **lepton-nucleon scattering**
- **next leading order measurements**
  - Q^2 evolution of quark polarization
  - high p_T hadron pair measurement
  - open charm measurement

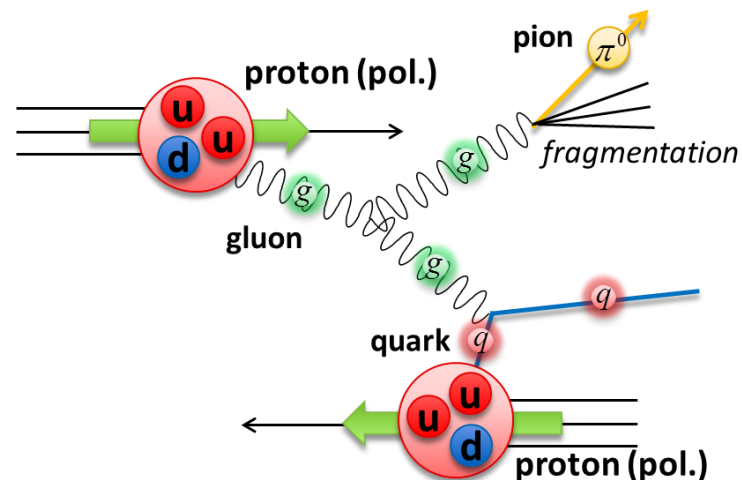### Complementary approaches for ΔG

polarized *p-p* experiment

- **direct contributions from g-q and g-g scattering**
- **various channels for ΔG measurement**
  - π^0
  - open heavy quarks *(this talk)*
  - direct γ
  - etc...

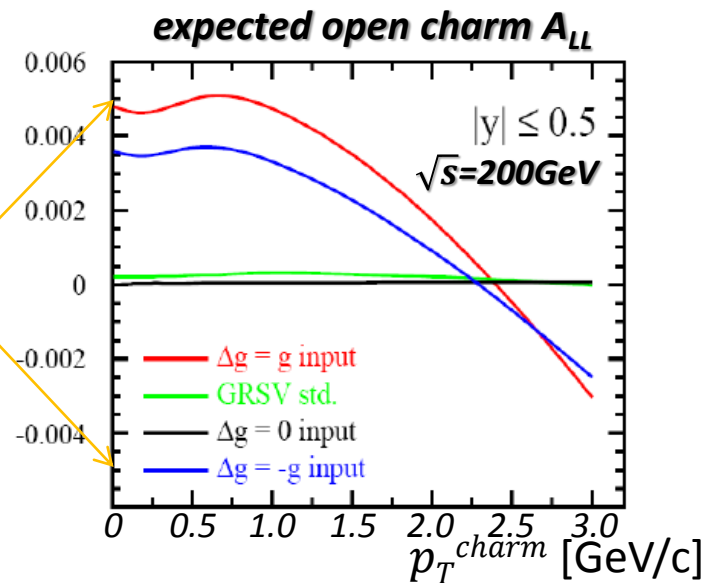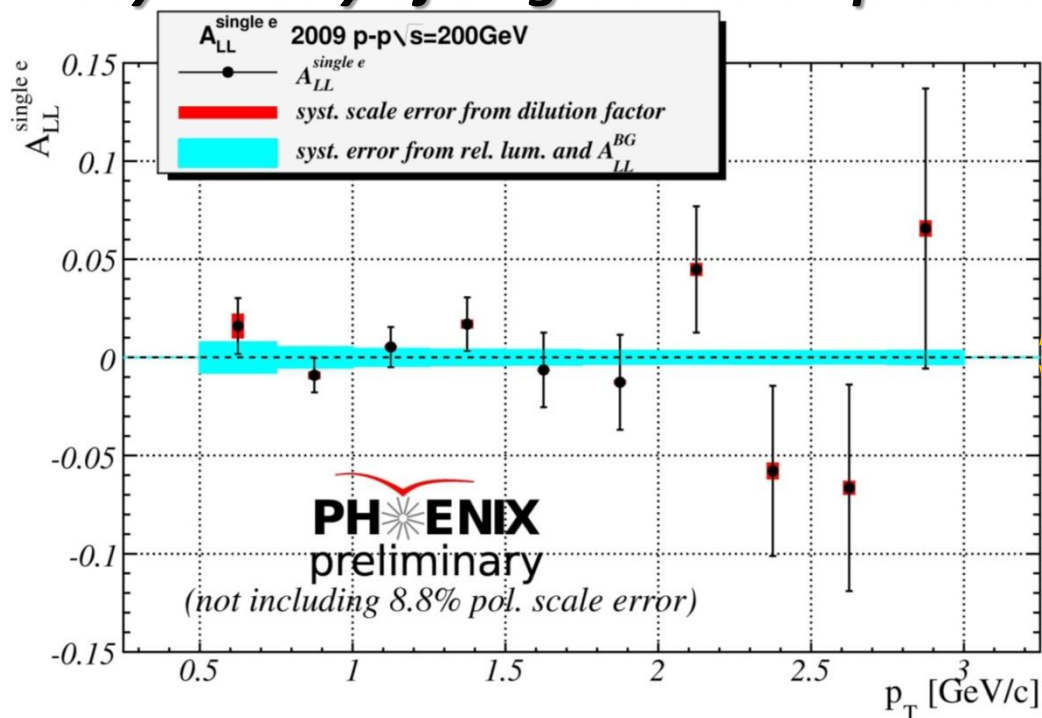**polarized *p-p* experiment**

Spin Asymmetry for Single Electron Production

spin asymmetry of single electron production

expected open charm A_{LL}

Background for the Single Electron Measurement
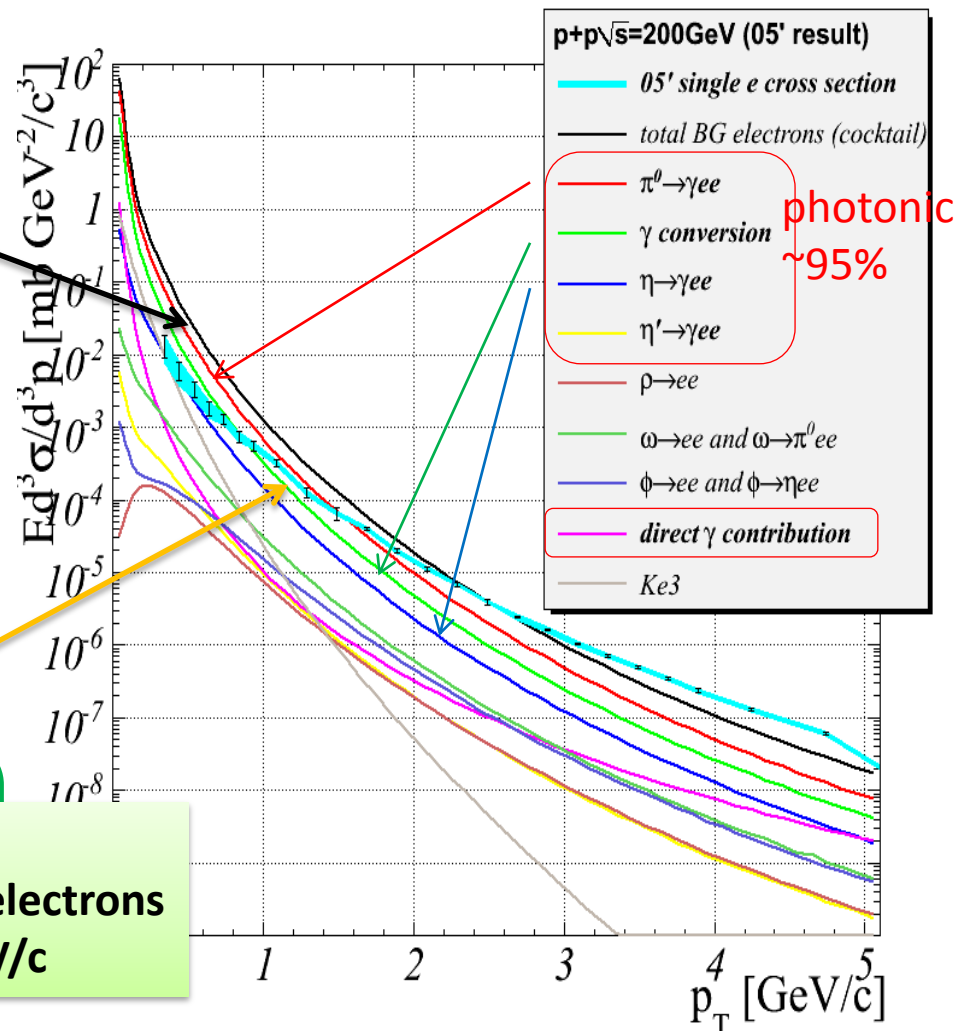
dominant background

PHENIX 05' single e and BG cross section

- **photon conversion** **background**

$$\pi^0(\eta) \rightarrow \gamma\gamma \quad \gamma \rightarrow e^+ e^- \text{ (in material)}$$

- **Dalitz decay**

$$\pi^0(\eta) \rightarrow \gamma \, e^+ e^-$$

- **direct photon conversion**
  small, but significant at high p_T
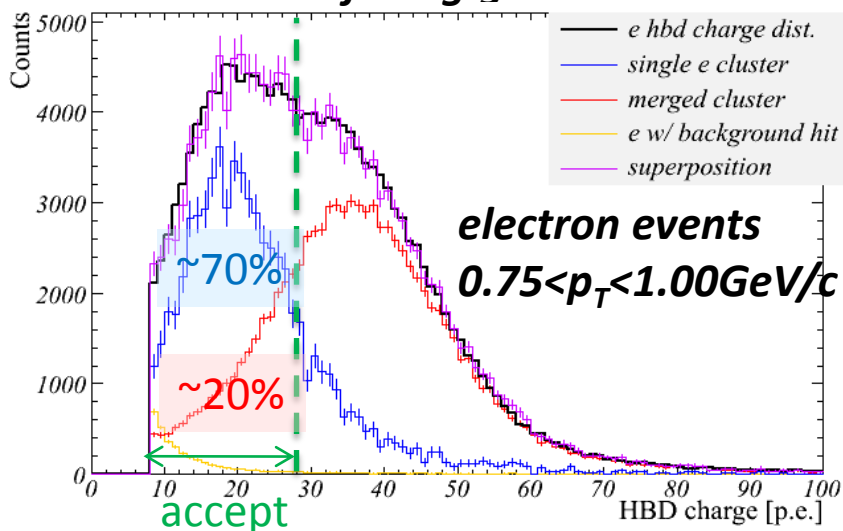
non-photonic electron

- **Heavy meson decay**

$$D \rightarrow e^{\pm} + X \qquad \text{(signal)}$$

- **Kaon decay**

$$K_{e3} : K^{\pm} \rightarrow \pi^0 \, \nu_e \, e^{\pm}$$

- **vector meson decay**

$$\omega, \rho, \phi, J/\psi, \Upsilon \rightarrow e^+ e^-$$

~ a few% of non-photonic electrons at $p_T > 0.50$GeV/c

photonic ~95%

p+p√s=200GeV (05' result)
- *05' single e cross section*
- *total BG electrons (cocktail)*
- $\pi^0 \rightarrow \gamma ee$
- γ conversion
- $\eta \rightarrow \gamma ee$
- $\eta' \rightarrow \gamma ee$
- $\rho \rightarrow ee$
- $\omega \rightarrow ee$ and $\omega \rightarrow \pi^0 ee$
- $\phi \rightarrow ee$ and $\phi \rightarrow \eta ee$
- *direct γ contribution*
- Ke3

$E d^3\sigma/d^3p$ [mb GeV^{-2}/c^3]

p_T [GeV/c]

HBD clustering results distribution
reference charge distributions

electron events
$0.75 < p_T < 1.00\,GeV/c$

~70%

~20%

accept

- **electron analysis with HBD**
  - estimate the fractions of single e clusters and merged clusters by fitting HBD charge distribution
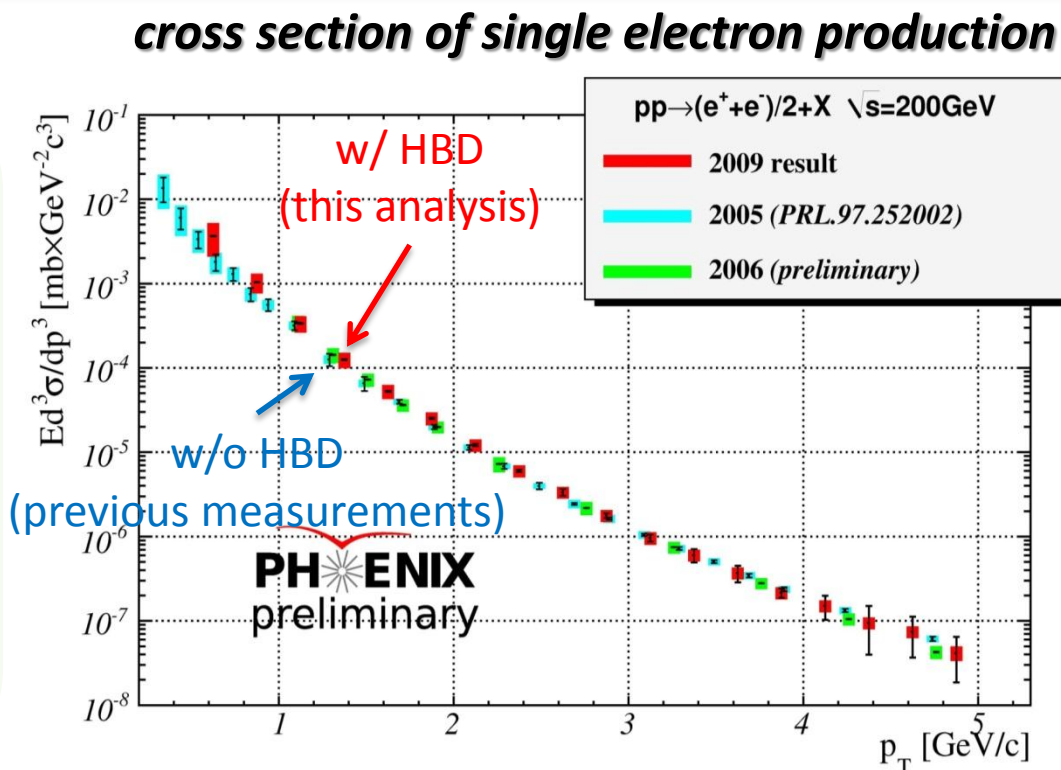 - reject merged clusters with HBD charge cut effectively

Yield of single electrons

- **Yield of single electrons is estimated with this method**

established a new analysis method for single electron analysis

reconstructed electrons

estimated single electrons
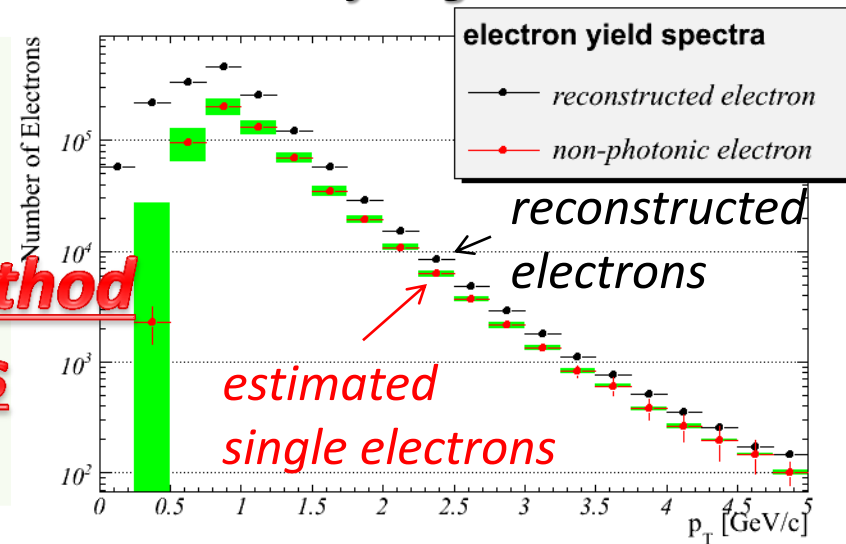
Check of Cross Section Spectrum

cross section of single electron production

- **cross section of single electron production**
  - good consistency with previous measurements
- **different analysis method from previous measurements**
  - converter & cocktail method for 2005 and 2006 results

w/ HBD (this analysis)

w/o HBD (previous measurements)

$pp \rightarrow (e^+ + e^-)/2 + X$ $\sqrt{s} = 200\,GeV$

- 2009 result
- 2005 (PRL.97.252002)
- 2006 (preliminary)

$Ed^3\sigma/dp^3$ [mb×GeV^{-2}c^3]

p_T [GeV/c]

PH✴ENIX preliminary

confirmation of the reliability of the analysis method with HBD